Topic E – Enviro Chemistry Part 8 – Waste

IB Chemistry

Topic E – Enviro

Hodder Ed - Talbot

E8 Waste - 2 hours

- E.8.1 Outline and compare the various methods for waste disposal. (3) *Examples include landfills and incineration.*
- E.8.2 Describe the recycling of metal, glass, plastic and paper products, and outline its benefits. (2)
- E.8.3 Describe the characteristics and sources of different types of radioactive waste. (2) *Include both low-level and high-level radioactive waste.*
- E.8.4 Compare the storage and disposal methods for different types of radioactive waste. (3)

- E.8.1 Outline and compare the various methods for waste disposal. (3) *Examples include landfills and incineration.*
- Municipal Solid Waste (MSW) is more commonly known as household garbage (or rubbish).
- The most common methods of disposal are:
  - Landfill sites (burying the waste)
  - Incineration (burning the waste)
  - Both methods are potentially damaging
  - Recycling waste is advantageous because removes the need to dispose of waste and cuts down on the need for non-renewable resources

E8.1 – Landfill Materials

- MSW falls into five categories
  - Food and kitchen waste and plant waste – biodegradable
  - Recyclable materials – glass, plastic, paper, etc
  - Composite wastes – mixtures of materials such as clothing and packaging materials – difficult to recycle
  - Inert wastes – rubble, debris, etc
  - Hazardous wastes – paints, garden chemicals, batteries, light bulbs, medicines

E8.1 - Landfill

- Landfills are designed to limit surface water (rain, runoff, etc) from passing through and leaching out harmful materials.
- Sites chosen are often made of clay – a low permeable soil so ground water movement is small
- Pits are lined with plastic, gravel, and a drainage system
  - This ensures that polluted water that accumulates (leachate) can be collected and disposed of properly
  - When full, the site is covered with the same layer to keep rain water out.

E8.1 – Landfill Gases

- When waste is added to site
  - At first, when O_2 is present, aerobic bacteria work on the organic material producing CO_2
  - When O_2 used up, anaerobic decomposition occurs and generates CH_4, H_2S, and H_2.
    - These gases can accumulate below ground so an ventilation system must be constructed
    - Air can be pumped into the landfill in order to increase the aerobic bacteria decomposition

E8.1 – Landfill Lechate

- The liquid leachate can contain **heavy metals** and **cyanide** and must be extracted from the landfill via the drainage system.
- The liquid must be treated by chemical or biological means to remove pollutants before re-entering waterways (discussed previously)
  - Heavy metal precipitation (E6)
- The **cyanide** can be removed by oxidation with sodium chlorate
  - $NaCN + NaOCl \rightarrow NaCNO + NaCl$
  - $2NaCNO + 3NaOCl + H_2O \rightarrow 3NaCl + N_2 + 2NaHCO_3$

E8.1 - Incineration

- Incineration has many advantages
  - Removes bulk from solid waste
  - Resultant ash has a uniform composition that can be more densely packed into landfills
  - Can be burned for power generation
- However, the flu gas must be thoroughly cleaned before being allowed to enter the environment as it contains CO, HCl, HCN, organics, heavy metals, and particulates
  - Two types of incinerators are the Rotary-kiln and Fluidized-bed.

E8.1 – Rotary-kiln Incinerator

- Rotating chambers are used to allow movement of waste and to ensure that all of the waste is exposed to air.
- Most of the waste is combusted to form gases
  - Passed to 'afterburner' to ensure that solid particulates are fully combusted
  - Gases are then 'scrubbed' to remove pollutants
- Remaining solid waste drops out of the kiln and is cooled with water, recyclable materials can be reclaimed from this solid waste.

E8.1 – Fluidized-bed Incinerator

- A sand bed is used to allow hot air to be basted in.
  - Separates the sand grains, allowing air between them
  - The sand is suspended on the air currents and it behaves like a fluid, flowing and circulating.
  - Ground-up waste is introduced to the sand bed where it's suspended and the air is mixed throughout ensuring that maximum surface area of the waste particles is exposed to air for combustion

E8.1 – Incinerator Air Pollution

- Most of the carbon present in waste (mostly in organic material and plastics) is converted into CO_2 in the incinerator.
- This is arguably preferable to landfills where methane is formed.
  - If the methane is not reclaimed as fuel it enters the atmosphere as a green house gas with a very high GWP (higher than CO_2)
- Other flu gas pollutants are removed in procedures described in E1.

E8.2 - Recycling

- E.8.2 Describe the recycling of metal, glass, plastic and paper products, and outline its benefits. (2)
- Recycling waste is beneficial as it
  - Reduces the bulk of land fills (as in incineration)
  - Conserves non-renewable resources
  - Requires less energy than manufacturing
  - VOC's and CO_2 are not produced during production
  - Crude oil is not consumed to produce
  - No water pollution from paper generation

E8.2 – Glass Recycling

- Glass is separated according to color
- Glass broken up into small pieces called 'cullet'
- Cullet easily melted and remolded into new bottles, jars, or glass fibers for insulation
- 'New' glass sometimes includes a percentage of cullet, to help reduce energy costs since cullet melts at a lower temperature than the raw materials for glass manufacture

E8.2 – Metal Recycling

- Metals retain physical properties when recycled
- The metals (aluminum, steel, etc) can be used for exactly the same purposed as the newly extracted metals but consume less raw materials and energy
- Magnetic materials can easily be separated from non-magnetic materials (ex: iron containing)

E8.2 – Aluminum Recycling

- Aluminum Recycling:
  - The cost of collecting, cleaning, re-melting and remolding aluminum waste is less than that of extracting new aluminum
  - Not all scrap aluminum is actually recycled as producers are reluctant to collect and clean scrap metal.
  - Aluminum is stockpiled because if energy costs rise in the future, producers will be more willing to recycle it

E8.2 – Steel Recycling

- Recycling steel reduces air and water pollution.
- The Basic Oxygen Process for steel manufacture requires that some scrap steel is added to the furnace, so steel manufactured in this way will contain some recycled metal
- Other scrap steel can be melted in an electric arc furnace which uses powerful electric currents to melt the steel ready for remolding.

E8.2 – Plastic Recycling

- The advantages in recycling plastics
  - Manufacturing plastics consumes non-renewable crude oil
  - Manufacturing plastics consumes large amounts of energy, emits CO_2 and other pollutants like VOC's
  - Most plastics do not decompose so t hey will be present in landfills for thousands of years
  - If plastics are incinerated they can release harmful toxins such as dioxins into the atmosphere

E8.2 - Polymers

- Most household plastics (like packaging) are **thermoplastic polymers** which means that they can be repeatedly melted and re-molded
- When plastics are mixed (differing lengths of hydrocarbon chains) the resultant structure is not uniform as contains weaknesses
- **Depolymerization** is used to recover useful monomers and is completed by treating plastics with chemical agents. But it is restricted to condensation polymers (where addition is the bulk of waste).
  - **Prolysis** is thermal degradation in the absence of oxygen to produce short chain HC's for fuel

B8.2 – Biodegradable Plastics

- Plastics are synthetic so cannot be decomposed by bacteria since they lack the enzymes to digest them
- But if the structure of the polymer is modified
  - Possible to produce a plastic which can decompose in a landfill
  - Possible to produce plastics that are designed to degrade under photochemical reactions (sun)
- If biodegradable plastics are recycled, when mixed with strong polymers, weaken the overall structure so they must be separated

E8.3/4 – Radioactive Wastes

- E.8.3 Describe the characteristics and sources of different types of radioactive waste. (2) *Include both low-level and high-level radioactive waste.*
- E.8.4 Compare the storage and disposal methods for different types of radioactive waste. (3)
- **Radioactivity** is the release of radiation from the nucleus of an atom as it changes, or decays, into a different element
  - Nuclei decay in order to stabilize their structure
  - Reduces neutron:proton ratio in nucleus
  - Three types: alpha, beta, gamma

E8.3/4 – Alpha Radiation

- Alpha radiation is the most harmful type, as alpha particles are relatively heavy and slow moving, making them more likely to ionize nearby atoms
  - Composed of two protons and two neutrons
- Uranium-238 decays by ejecting an α (alpha)

$$_{92}^{238}U \rightarrow {}_{90}^{234}U + {}_{2}^{4}He$$

- Poisoning by α radiation is unlikely since clothing and human skin is able to prevent penetration. BUT if α-emitting material is ingested or inhaled, then serious radiation poisoning results

E8.3/4 – Beta Radiation

- Beta radiation consists of high-energy electrons formed from a neutron tranmuting into a proton and high-speed electron.
- Cesium-137 nucleus decays into a Barium-137 nucleus

$$_{55}{}^{137}Cs \rightarrow {}_{56}{}^{137}Ba + {}_{-1}{}^{0}e^{-}$$

- Beta radiation can penetrate clothing and body tissues. Exposure to beta radiation outside the body is potentially harmful, but inhalation and ingestion pose the highest risk of harm

E8.3/4 – Gamma Radiation

- Gamma radiation is usually released in addition to either alpha or beta decay, since these decay types often leave the nucleus in an energetically 'excited' state.
- Energy is emitted in the form of gamma radiation, allowing nucleus to return to ground state

$$_{53}^{131}I \rightarrow {}_{54}^{131}U + {}_{-1}^{0}e^{-} + \gamma$$

- Gamma radiation is weakly ionizing, but highly penetrating. The likelihood of harm increases with prolonged exposure. Can penetrate metal.

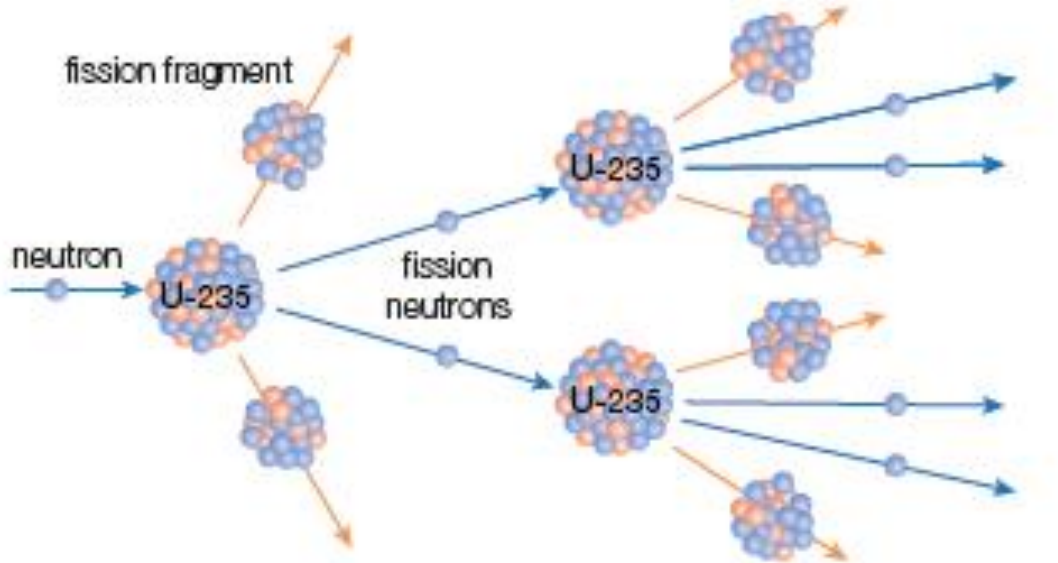
Radioactive wastes are stored in deep sites to l imit exposure to humans, plants, and animals

E8.3/4 – Nuclear Power Waste

- Radioactive waste is produced as a by-product of nuclear generation.
- Nuclear fuel (uranium, or plutonium) undergoes a process of nuclear fission where the nucleus is broken apart to form two smaller nuclei.
- The process generates large amounts of heat used to boil water and produce steam.

E8.3/4 – Nuclear Fission

- **Nuclear fission** typically involves the nucleus of a U-235 atom breaking apart and releasing fast moving neutrons. These neutrons move through uranium colliding with other nuclei, which in turn cause them to split apart. A chain reaction occurs.



E8.3/4 – Nuclear Waste

- Hazards from nuclear waste
  - Nuclear accidents or accidental exposure to high-level nuclear waste
    - Acute radiation poisoning, possibly death in a matter of days
  - Can be limited by careful reactor design and regulation of waste disposal.
- Many people are worried about the possible exposure and say it's not worth the possible environmental cost as well.

E8.3/4 – Disposal of Nuclear Waste

- **<u>High Level Waste</u>**:
- When the uranium-235 fuel in a reactor is used up, the fuel rods must be disposed
- The rods are extremely radioactive as they contain actinides (^{235}U, ^{239}Pu) with are radioactive because of the production of fission products such as ^{90}Sr and ^{137}Cs which emit β-particles and γ-rays respectively.
- High level wastes also contain ^{239}Pu, which is an activation product and used to make nuclear weapons

E8.3/4 – High Level Nuclear Waste

- Problems with high-level waste
  - Long half-lives
  - Dangerous levels of radioactivity
- High-level wastes can be treated by a process called **vitrification** in which the resulting liquid glass can be poured into steel containers
  - The glass solidifies into cylinders with the radioactive materials fused into the glass structure which is fully waterproof (cannot leache)
  - The vitrified material is still radioactive and must be stored properly (most stored temporarily) but if stored in deep bunkers could minimize harm

E8.3/4 – Low-level Nuclear Waste

- Even material that has not been present near the reactor are designated as radioactive waste, and their disposal is monitored.
  - Protective clothing, paper filters, plastic bags, etc
  - The radioactivity is low-level and short lived
  - Treated in a similar fashion as MSW – it's incinerated to reduce it's volume, and then is buried in dedicated landfills where it can slowly decay and become stable during a *relatively* quick process.

E8.3/4 – Nuclear Medical Waste

- Radioactive isotopes are used in numerous medical applications
  - **Medicines or diagnostic tools** – short ½ life substances are used. Technetium is used as a tracer. Iodine-131 is used to treat thyroid cancers (since the gland absorbs iodine)
  - **Radiotherapy** – long ½ life substances like cesium-137 are used to generate radiation in machines used for radiotherapy
  - **X-rays** for radiography – long ½ life substances such as cobalt-60 and iridium-192 are used to generate X-rays for imagine
- Medical gloves and clothing are considered low-level, isotopes from defunct X-ray machines are considered high-level